



# SEMICONDUCTOR INTEGRATED CIRCUIT

## *CROSS REFERENCE TO RELATED APPLICATION*

This application is based upon and claims the benefit of priority from Japanese Patent  
5 Application No. 2003-375276, filed on November 5, 2003, the entire contents of which are  
incorporated herein by reference.

## *BACKGROUND OF THE INVENTION*

### *1. Field of the Invention*

10 The present invention relates to a semiconductor integrated circuit having a  
temperature detector..

### *2. Description of the Related Art*

An SRAM has been conventionally used as a work memory of portable equipment  
15 such as a cellular phone. However, memory capacity necessary for portable equipment has  
been increasing year after year. Therefore, a DRAM having dynamic memory cells or a  
pseudo SRAM is adopted as a work memory in recent years. A DRAM can have larger  
memory capacity as a work memory with the same cost since a memory cell thereof is smaller  
than a memory cell of the SRAM.

20 Meanwhile, a memory mounted on a cellular phone needs to be low in power  
consumption in order to make the battery life long. A low standby current is especially  
important in a cellular phone in order to increase the continuous standby time. The DRAM  
and the pseudo SRAM require regular refresh operation of memory cells even while the  
portable equipment is in nonoperation, and the refresh operation is a factor of increasing the  
25 standby current. Therefore, various methods are devised in order to reduce the standby

current in the DRAM and the pseudo SRAM.

For example, some technique has been proposed for reducing the standby current, by taking advantage of the characteristics of the dynamic memory cell that has the data retention time which gets longer as the chip temperature is higher, and setting a long refresh 5 interval when the chip temperature is lower than a certain boundary temperature to reduce the frequency of the refresh operation (disclosed in, for example, Japanese Unexamined Patent Application Nos. Hei 5-266658, Hei 7-73668, and Hei 3-207084).

Fig. 1 shows temperature-dependent data retention time of a dynamic memory cell. As described above, the lower the chip temperature is, the longer the data retention time of 10 the dynamic memory cell is. It is possible to reduce the standby current by changing the refresh interval according to the boundary temperature  $T_{th}$  detected by a temperature detector.

Fig. 2 shows a problematic example of a conventional semiconductor integrated circuit having a temperature detector. When the semiconductor integrated circuit operates 15 around a boundary temperature  $T_{th}$ , an output of the temperature detector varies in a short cycle if heat generation due to the operation of internal circuits and heat release due to operation termination of the internal circuits are repeated. As a result, a control circuit connected to an output of the temperature detector changes its operating state (low power 20 operation and normal operation) in response to the output of the temperature detector. This switching operation increases current consumption of the control circuit, so that an effect of reducing the standby current is lowered.

Fig. 3 shows another example of a problem of the conventional semiconductor integrated circuit having the temperature detector. When the operation and nonoperation of the internal circuits of the semiconductor integrated circuit are repeated around the boundary 25 temperature  $T_{th}$ , the temperature detector sometimes malfunctions since it detects power

supply noises as temperature variation. Therefore, the output of the temperature detector varies with a short cycle. At this time, since, as in Fig. 2, the operating state of the control circuit connected to the output of the temperature detector is switched over with a short cycle, current consumption of the control circuit increases. Further, the operating state of the 5 control circuit shown in Fig. 3 is switched over irrespective of the chip temperature, so that the semiconductor integrated circuit malfunctions.

#### *SUMMARY OF THE INVENTION*

It is an object of the present invention to reduce current consumption of a 10 semiconductor integrated circuit having a temperature detector.

It is another object of the present invention to prevent malfunction of a temperature detector due to noises, thereby preventing malfunction of a semiconductor integrated circuit.

According to one of the aspects of the semiconductor integrated circuit of the present invention, a temperature detector sets the level of a temperature detecting signal to a 15 level indicating a high temperature state when detecting that a chip temperature shifts from low to high and is higher than a first boundary temperature. Further, the temperature detector sets the level of the temperature detecting signal to a level indicating a low temperature state when detecting that the chip temperature shifts from high to low and is lower than a second boundary temperature that is different from the first boundary 20 temperature. A control circuit changes its own operating state according to the level of the temperature detecting signal.

In the semiconductor integrated circuit described above, the boundary temperature based on which the operating state of the control circuit is changed from a certain state to another state is different from the boundary temperature based on which the operating state 25 of thereof is changed from another state to a certain state, so that it is able to prevent the

operating state of the control circuit from frequently switched over even when the chip temperature fluctuates around the boundary temperature. As a result, current consumption of the control circuit due to the switching operation can be reduced. Further, since the first boundary temperature and the second boundary temperature set a buffer zone, the 5 temperature detector does not detect power supply noises or the like generated due to the operation of internal circuits as temperature variation. As a result, it is possible to prevent malfunction of the temperature detector and of the semiconductor integrated circuit.

According to another aspect of the semiconductor integrated circuit of the present invention, the temperature detector maintains the level of the temperature detecting signal 10 while the chip temperature is between the first boundary temperature and the second boundary temperature.

In the semiconductor integrated circuit described above, maintaining the level of the temperature detecting signal while the chip temperature is between the first boundary temperature and the second boundary temperature makes it possible to prevent the 15 operating state of the control circuit from frequently switched over, which can reduce current consumption due to the switching of the control circuit.

According to another aspect of the semiconductor integrated circuit of the present invention, the temperature detector has a temperature detecting unit, a first differential amplifier, a second differential amplifier, and a flipflop. The temperature detecting unit has 20 a resistor and a bipolar transistor that are connected in series between a power supply line and a ground line, and generates a detection voltage corresponding to the chip temperature from a connecting node of the resistor and the bipolar transistor. The first differential amplifier compares a first reference voltage corresponding to the first boundary temperature with the detection voltage. The second differential amplifier compares a second reference 25 voltage corresponding to the second boundary temperature with the detection voltage. The

flipflop generates the level of the temperature detecting signal according to results of the comparisons from the first and second differential amplifiers.

In the semiconductor integrated circuit described above, it is possible to monitor the chip temperature as the detection voltage by taking advantage of temperature-dependent changes in a threshold voltage of the bipolar transistor. The first and second differential amplifiers are used to compare the detection voltage with the first and second reference voltages corresponding to the first and second boundary temperatures respectively, which makes it possible to detect the change in the chip temperature accurately with a simple circuit and to surely switch over the operating state of the control circuit.

According to another aspect of the semiconductor integrated circuit of the present invention, the temperature detector has a temperature detecting unit, a basic differential amplifier, a first differential amplifier, a second differential amplifier, and a flipflop. The temperature detecting unit has a resistor and a bipolar transistor that are connected in series between a power supply line and a ground line, and generates a detection voltage corresponding to the chip temperature from a connecting node of the resistor and the bipolar transistor. The basic differential amplifier compares a basic reference voltage and the detection voltage to output a result of the comparison as a basic detection voltage. The first differential amplifier compares a first reference voltage corresponding to the first boundary temperature with the basic detection voltage. The second differential amplifier compares a second reference voltage corresponding to the second boundary temperature with the basic detection voltage. The flipflop generates the level of the temperature detecting signal according to results of the comparisons from the first and second differential amplifiers.

Moreover, the change in the detection voltage (basic detection voltage) inputted to the first and second differential amplifiers is made steep by the basic differential amplifier's amplification of the detection voltage outputted from the temperature detecting unit. This

enables secure generation of the temperature detecting signal when the first and second boundary temperatures are close to each other, even if the fluctuation or others in the manufacturing conditions of the semiconductor integrated circuit causes variances in the characteristics of the first and second differential amplifiers, and the variances cause an offset 5 voltage.

According to another aspect of the semiconductor integrated circuit of the present invention, a voltage generator generates a plurality of kinds of voltages. A switch circuit selects two kinds from the plurality of kinds of voltages to output the selected voltages as a first and a second reference voltage. A ROM circuit presets the voltages to be selected by the 10 switch circuit.

In the semiconductor integrated circuit described above, plurality of the first and second reference voltages can be generated by selecting the switch circuit according to values set by the ROM circuit. This makes it possible to manufacture a semiconductor integrated circuit with an optimum characteristic in conformity with fluctuations in the manufacturing 15 conditions and with the product specifications.

According to another aspect of the semiconductor integrated circuit of the present invention, a memory array has dynamic memory cells. The control circuit is a refresh timer configured to change a generation cycle of a refresh request signal for refreshing the memory cell, according to the level of the temperature detecting signal.

20 In the semiconductor integrated circuit described above, the refresh cycle of the memory cell is changed according to the chip temperature, which makes it possible to reduce power consumption of the semiconductor integrated circuit.

According to another aspect of the semiconductor integrated circuit of the present invention, a command decoder decodes a read command signal and a write command signal 25 that are access requests supplied via an external terminal. An operation control circuit

outputs a timing signal for putting the memory array into operation in order to execute an access operation in response to the read command signal and the write command signal and a refresh operation in response to the refresh request signal. The operation control circuit has an arbiter configured to determine which one of the access operation and the refresh 5 operation is to be given priority when the read command signal or the write command signal conflict with the refresh request signal.

The refresh timer can be operated efficiently to reduce standby current since the semiconductor integrated circuit described above has the arbiter configured to determine which of the access operation and the refresh operation is executed first when the read 10 command or the write command conflict with the refresh command.

According to another aspect of the semiconductor integrated circuit of the present invention, during a normal operation mode, a command decoder decodes a read command signal and a write command signal that are access requests supplied via an external terminal and a self refresh command signal for changing the normal operation mode to a self refresh 15 mode. An operation control circuit outputs a timing signal for putting the memory array into operation in order to execute an access operation in response to the read command signal and the write command signal and a refresh operation in response to the refresh request signal. A refresh timer starts operating when the command decoder decodes the self refresh command signal.

20 In the semiconductor integrated circuit described above, it is possible to efficiently operate the refresh timer to reduce standby current (self refresh current) since the semiconductor integrated circuit has the self refresh mode.

#### *BRIEF DESCRIPTION OF THE DRAWINGS*

25 The nature, principle, and utility of the invention will become more apparent from the

following detailed description when read in conjunction with the accompanying drawings in which like parts are designated by identical reference numbers, in which:

Fig. 1 is a characteristic chart showing temperature-dependent data retention time of a dynamic memory cell;

5 Fig. 2 is an explanatory chart showing a problematic example of a conventional semiconductor integrated circuit having a temperature detector;

Fig. 3 is an explanatory chart showing another problematic example of the conventional semiconductor integrated circuit having the temperature detector;

10 Fig. 4 is a block diagram showing a first embodiment of the semiconductor integrated circuit of the present invention;

Fig. 5 is a block diagram showing a temperature detector and a refresh timer shown in Fig. 4 in detail;

Fig. 6 is a waveform chart showing the operation of the temperature detector shown in Fig. 5;

15 Fig. 7 is a waveform chart showing the operation of the temperature detector and the refresh timer according to variation in chip temperature in the first embodiment;

Fig. 8 is a block diagram showing a second embodiment of the semiconductor integrated circuit of the present invention;

20 Fig. 9 is a circuit diagram showing a reference voltage setting circuit and a reference voltage generator shown in Fig. 8 in detail;

Fig. 10 is a circuit diagram showing an essential part of a third embodiment of the semiconductor integrated circuit of the present invention;

Fig. 11 is a waveform chart showing the operation of a temperature detector shown in Fig. 10;

25 Fig. 12 is a block diagram showing a fourth embodiment of the semiconductor

integrated circuit of the present invention;

Fig. 13 is a circuit diagram showing a temperature detector shown in Fig. 12 in detail;

Fig. 14 is a waveform chart showing the operation of the temperature detector and a refresh timer according to variation in chip temperature in the fourth embodiment; and

5 Fig. 15 is a block diagram showing a fifth embodiment of the semiconductor integrated circuit of the present invention.

#### *DESCRIPTION OF THE PREFERRED EMBODIMENTS*

Hereinafter, embodiments of the present invention will be explained using the drawings. The double circles in the drawings represent external terminals. In the drawings, 10 each signal line shown by the heavy line is constituted of a plurality of lines. Part of a block to which the heavy line is connected is constituted of a plurality of circuits. The same reference numerals and symbols as those of the external terminals are used to designate signals supplied via the external terminals. The same reference numerals and symbols as 15 those of the signals are used to designate signal lines through which the signals are transmitted.

Fig. 4 shows a first embodiment of the semiconductor integrated circuit of the present invention. This semiconductor integrated circuit is formed on a silicon substrate as a pseudo SRAM, using a CMOS process. The pseudo SRAM has a memory core of a DRAM 20 and an interface of an SRAM. The pseudo SRAM executes a refresh operation periodically inside a chip without receiving an external refresh command and retains data written to memory cells. The pseudo SRAM is used as a work memory mounted on, for example, a cellular phone. A read operation and a write operation are executed in response to command signals CMD (a read command signal and a write command signal) supplied via an 25 external terminal.

The pseudo SRAM has a command input circuit 10, a reference voltage generator 12, a temperature detector 14, a refresh timer 16, a refresh address generator 18, an address input circuit 20, a data input/output circuit 22, an operation control circuit 24, an address switching circuit 26, and a memory core 28. Note that only essential signals necessary for 5 explaining the present invention are shown in Fig. 4.

The command input circuit 10 (command decoder) receives the command signal CMD (for example, a chip enable signal /CE, a write enable signal /WE, an output enable signal /OE, or the like) supplied via a command terminal. The command input circuit 10 decodes the received command signal CMD (access request) to output an internal command 10 signal ICMD for putting the memory core 28 into operation.

The reference voltage generator 12 generates a threshold voltage  $V_{th1}$  (first reference voltage) and a threshold voltage  $V_{th2}$  (second reference voltage). The threshold voltages  $V_{th1}$ ,  $V_{th2}$  correspond to a first boundary temperature  $T_{th1}$  and a second boundary temperature  $T_{th2}$  which will be described later, respectively.

15 The temperature detector 14 sets a temperature detecting signal TDET to low level indicating a high temperature state when detecting that the chip temperature of the pseudo SRAM shifts from a low temperature to a high temperature to be higher than the boundary temperature  $T_{th1}$  (represented by the threshold voltage  $V_{th1}$ ). The temperature detecting circuit 14 sets the level of the temperature detecting signal TDET to high level indicating a low 20 temperature state when detecting that the chip temperature shifts from a high temperature to a low temperature to be lower than the boundary temperature  $T_{th2}$  (represented by the threshold voltage  $V_{th2}$ ). The temperature detector 14 maintains the level of the temperature detecting signal TDET when the chip temperature is between the boundary temperatures  $T_{th1}$ ,  $T_{th2}$ . The boundary temperature  $T_{th1}$  is higher than the boundary temperature  $T_{th2}$ .

25 The refresh timer 16 generates in a predetermined cycle a refresh request signal

RREQ for refreshing a memory cell MC. The refresh timer 16 sets a timer cycle long when the temperature detecting signal TDET is at high level and sets the timer cycle short when the temperature detecting signal TDET is at low level. In other words, the output frequency of the refresh request signal RREQ is low when the chip temperature is low and is high when the 5 chip temperature is high.

The refresh address generator 18 executes a count operation in response to the refresh request signal RREQ to output a refresh address signal RFA constituted of a plurality of bits. The refresh address signal RFA is a row address signal for selecting a word line WL.

The address input circuit 20 receives an address signal ADD supplied from an 10 address terminal and outputs the received signal as a row address signal RA and a column address signal CA. The row address signal RA is used for selecting the word line WL. The column address signal CA is used for selecting a bit line BLZ (or BLX).

The data input/output circuit 22 outputs read data, which is transferred from the memory core 28 via a common data bus CDB, to a data terminal DQ (for example, 16 bits) at 15 the time of the read operation. The data input/output circuit 22 receives write data supplied via the data terminal DQ to transfer the received data to the memory core 28 via the common data bus CDB at the time of the write operation.

The operation control circuit 24 has an arbiter 25 that determines to which one of the internal command signal ICMD and the refresh request signal RREQ, which are inputted 20 asynchronously, priority should be given when they conflict with each other. The operation control circuit 24 outputs a refresh signal REFZ when the refresh operation is executed in response to the refresh request signal RREQ. The refresh operation is executed by the arbiter 25 between the read operations or the write operations executed in response to the read command or the write command supplied from an external part of the pseudo SRAM. In 25 other words, the refresh operation is automatically executed inside the pseudo SRAM. The

operation control circuit 24 outputs a timing signal TIMING for determining the operation timing of a plurality of control circuits (a word decoder WDEC, a sense amplifier SA, and so on to be described later) in the memory core 28, in response to the internal command signals ICMD (the read command signal and the write command signal) or the refresh request signal

5 RREQ (refresh command signal) to which the arbiter 25 has determined to give priority.

The address switching circuit 26 outputs the row address signal RA as an internal row address signal IRA while receiving the low level refresh signal REFZ (during the read operation, the write operation, or a standby period). The address switching circuit 26 outputs the refresh address signal RFA as the internal row address signal IRA while receiving

10 the high level refresh signal RFEZ (during the refresh operation). This means that the externally supplied row address signal RA is selected during the read operation, the write operation, and the standby period, and the internally generated refresh address signal RFA is selected during the refresh operation.

The memory core 28 has the word decoder WDEC, the sense amplifier SA, a  
15 precharging circuit PRE, a memory array ARY, a column decoder CDEC, a sense buffer SB, and a write amplifier WA. The operating timings of the circuits except the memory array ARY are set by the timing signals TIMING respectively.

The word decoder WDEC selects the word line WL corresponding to the internal row address signal IRA. The sense amplifier SA amplifies a voltage difference between bit lines  
20 BLZ, BLX at the time of the read operation, the write operation, and the refresh operation.

The precharging circuit PRE sets the bit lines BLZ, BLX to predetermined voltages while the memory core 28 is in nonoperation.

During the read operation and the write operation, the column decoder CDEC selects a column switch for connecting the bit lines BLZ, BLX and the data bus DB according to the  
25 column address signal CA, and turns on the selected column switch in synchronization with a

column line control signal CLZ. The sense buffer SB amplifies a signal amount of the read data on the data bus DB at the time of the read operation to output it to the common data bus CDB. The write amplifier WA amplifies a signal amount of the write data on the common data bus CDB at the time of the write operation to output it to the data bus DB.

5 The memory array ARY has the plural dynamic memory cells MC arranged in matrix, and the plural word lines WL and the plural bit line pairs BLZ, BLX connected to the memory cells MC. Each of the memory cells MC, which are the same as typical DRAM memory cells, has a capacitor (memory node) for retaining data as charges and a transfer transistor disposed between this capacitor and the bit line BL. A gate of the transfer transistor is  
10 connected to the word line WL.

Fig. 5 shows the temperature detector 14 and the refresh timer 16 shown in Fig. 4 in detail. The temperature detector 14 has a temperature detecting unit 14a, a first differential amplifier 14b, a second differential amplifier 14c, a flipflop 14d, and so on. The temperature detecting unit 14a has a resistor R1 (for example a diffusion resistance) and a  
15 bipolar transistor BP1 that are connected between an internal power supply line VII and a ground line VSS. The temperature detecting unit 14a generates a detection voltage corresponding to the chip temperature from a connecting node N01 of the resistor R1 and the bipolar transistor BP1. For example, a threshold voltage of the bipolar transistor BP1 lowers as the chip temperature rises, therefore, voltage drops at the node N01.

20 The differential amplifier 14b compares the threshold voltage Vth1 representing the first boundary temperature Tth1 and the detection voltage N01. An output node N02 of the differential amplifier 14b changes to high level when the detection voltage  $N01 < Vth1$ , and changes to low level when the detection voltage  $N01 > Vth1$ . The differential amplifier 14c compares the threshold voltage Vth2 representing the second boundary temperature Tth2 and the detection voltage N01. An  
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output node N04 of the differential amplifier 14c changes to high level when the detection voltage N01 > the threshold voltage  $V_{th2}$ , and changes to low level when the detection voltage N01 < the threshold voltage  $V_{th2}$ . Inverters connected to outputs of the differential amplifiers 14b, 14c, respectively, form and invert waveforms of the nodes N02, N04 and

5 output the inverted waveforms to the flipflop 14d via nodes N03, N05.

The flipflop 14d changes the temperature detecting signal TDET to low level when the node N03 changes from high level to low level, and changes the temperature detecting signal TDET to high level when the node N05 changes from high level to low level.

The refresh timer 16 has a ring oscillator 16a, a frequency divider 16b, and a selector 10 16c. The ring oscillator 16a has inverters of odd-number stages connected in cascade and outputs an oscillation signal with a predetermined cycle. The frequency divider 16b has 1/2 frequency dividers of plural stages connected in cascade for dividing the frequency of the oscillation signal. The selector 16c selects either one of the frequency divided signals outputted from predetermined two of the 1/2 frequency dividers according to the logic level 15 of the temperature detecting signal TDET and outputs the selected frequency divided signal as the refresh request signal RREQ. Note that the 1/2 frequency dividers outputting the frequency divided signals to be inputted to the selector 16c are not limited to the two 1/2 frequency dividers shown in the drawing but may be determined according to the design and specifications of the pseudo SRAM.

20 Fig. 6 shows the operation of the temperature detector 14 shown in Fig. 5. The temperature detecting unit 14a shown in Fig. 5 generates a voltage in the node N01 according to the chip temperature. When the chip temperature changes from a low temperature to a high temperature to exceed the boundary temperature  $T_{th2}$  (Fig. 6 (a)), the output node N04 of the differential amplifier 14c changes from high level to low level, and the 25 node N05 changes from low level to high level (Fig. 6 (b)). At this time, since the node N03 is

at high level, an output (TDET) of the flipflop 14d maintains high level (Fig. 6 (c)).

When the chip temperature changes from a low temperature to a high temperature to exceed the boundary temperature  $T_{th1}$  (Fig. 6 (d)), the output node N02 of the differential amplifier 14b changes from low level to high level, and the node N03 changes from high level 5 to low level (Fig. 6 (e)). At this time, since the node N05 is at high level, the output (TDET) of the flipflop 14d changes from high level to low level (Fig. 6 (f)).

Conversely, when the chip temperature changes from a high temperature to a low temperature to be lower than the boundary temperature  $T_{th1}$  (Fig. 6 (g)), the output node N02 of the differential amplifier 14b changes from high level to low level, and the node N03 10 changes from low level to high level (Fig. 6 (h)). At this time, since the node N05 is at high level, the output (TDET) of the flipflop 14d maintains low level (Fig. 6 (i)).

When the chip temperature changes from a high temperature to a low temperature to be lower than the boundary temperature  $T_{th2}$  (Fig. 6 (j)), the output node N04 of the differential amplifier 14c changes from low level to high level, and the node N05 changes 15 from high level to low level (Fig. 6 (k)). At this time, since the node N03 is at high level, the output (TDET) of the flipflop 14d changes from low level to high level (Fig. 6 (l)). Thus, the temperature detector 14 has a Schmitt trigger function and the temperature detecting signal TDET indicates a preceding value when the chip temperature is between the boundary temperatures  $T_{th1}$ ,  $T_{th2}$ .

20 Fig. 7 shows the operation of the temperature detector 14 and the refresh timer 16 according to the change in the chip temperature in the first embodiment. The temperature detecting signal TDET changes from high level to low level only when the chip temperature exceeds the boundary temperature  $T_{th2}$  and further exceeds  $T_{th1}$  (Fig. 7 (a)). Further, the temperature detecting signal TDET changes from low level to high level only when the chip 25 temperature goes lower than the boundary temperature  $T_{th1}$  and further goes lower than

Tth2 (Fig. 7 (b)). In other words, when the chip temperature fluctuates around the boundary temperature Tth1 (Fig. 7 (c)), the boundary temperature Tth2 (Fig. 7 (d, e)), and between the boundary temperatures Tth1, Tth2 (Fig. 7 (f, g)), the level of the temperature detecting signal TDET does not change. In this manner, in the present invention the boundary temperatures 5 Tth1, Tth2 set a buffer zone, so that it is possible to prevent the output level of the temperature detecting signal TDET from frequently changing due to slight change in the chip temperature or power supply noises that are caused by the operation of the internal circuits of the pseudo SRAM. Therefore, the operation of the temperature detector 14 can be more stabilized. As a result, it is possible to prevent malfunction of the temperature detector 14, 10 thereby preventing malfunction of the pseudo SRAM.

When the temperature detecting signal TDET is at high level, the refresh timer 16 makes the generation interval of the refresh request signal RREQ longer. At a low chip temperature, the data retention time of the memory cell MC gets long, so that data retained in the memory cell MC are not lost even the refresh frequency is lowered. On the other hand, 15 At a high chip temperature, the data retention time of the memory cell MC gets short, so that it is necessary to prevent loss of the data retained in the memory cell MC by increasing the refresh frequency. The change in the refresh frequency according to the chip temperature makes it possible to prevent unnecessary operation of the refresh timer 16 and so on to reduce the standby current. Moreover, it is possible to prevent the refresh cycle from 20 frequently switched when the temperature fluctuates around the boundary temperature Tth1 or Tth2. Consequently, it is able to prevent increase in current consumption of the temperature detector 14 and the refresh timer 16 and increase in the standby current which are caused by the switching operation.

In this embodiment described above, the logic level of the temperature detecting 25 signal TDET outputted by the temperature detector 14 is changed using the two boundary

temperatures  $T_{th1}$ ,  $T_{th2}$  as references, and the logic level of the temperature detecting signal TDET is maintained when the chip temperature is between the boundary temperatures  $T_{th1}$ ,  $T_{th2}$ , which makes it possible to prevent frequently changing the cycle of the refresh request signal RREQ even when the chip temperature fluctuates around the boundary temperature 5  $T_{th1}$  or  $T_{th2}$ . As a result, it is possible to lower the frequency of the switching operation in the refresh timer 16 for changing the cycle of the refresh request signal RREQ (the refresh cycle of the memory cell MC). Therefore, it is possible to reduce the standby current of the pseudo SRAM having the arbiter 25 that determines the order in which the access operation and the refresh operation are executed.

10 The temperature detecting unit 14a of the temperature detector 14 is capable of monitoring the chip temperature as the detection voltage  $N01$  by utilizing the temperature dependent change in the threshold voltage of the bipolar transistor BP1. Further, the differential amplifiers 14b, 14c compare the detection voltage  $N01$  with the threshold voltages  $V_{th1}$ ,  $V_{th2}$  corresponding to the boundary temperatures  $T_{th1}$ ,  $T_{th2}$  respectively, so 15 that the change in the chip temperature can be detected accurately with a simple circuit.

Fig. 8 shows a second embodiment of the semiconductor integrated circuit of the present invention. The same reference numerals and symbols are used to designate the same elements as the elements explained in the first embodiment, and detailed explanation thereof will be omitted. The semiconductor integrated circuit of this embodiment is formed 20 on a silicon substrate as a pseudo SRAM, using a CMOS process.

The pseudo SRAM has a reference voltage generator 30 in place of the reference voltage generator 12 of the first embodiment. Further, a reference voltage setting circuit 32 is additionally formed. The other configuration is substantially the same as that of the first embodiment.

25 The reference voltage setting circuit 32 outputs four-bit setting signals SET in order

to initially set respective values of threshold voltages  $V_{th1}$ ,  $V_{th2}$  to be generated by the reference voltage generator 30. The logic of the setting signals SET is fixed during manufacturing processes of the pseudo SRAM. The reference voltage generator 30 generates the threshold voltages  $V_{th1}$ ,  $V_{th2}$  having values according to the logic of the 5 setting signals SET.

Fig. 9 shows the reference voltage setting circuit 32 and the reference voltage generator 30 shown in Fig. 8 in detail. In this example, only circuits for generating the threshold voltage  $V_{th1}$  are shown. The pseudo SRAM has the same circuits as those in Fig. 9 for generating the threshold voltage  $V_{th2}$ .

10 The reference voltage setting circuit 32 has a ROM circuit 32a that outputs fuse signals FS1, FS0 whose logic is fixed during the manufacturing processes of the pseudo SRAM and a decoder 32b that decodes the fuse signals FS1, FS0 and outputs the setting signals SET (SET11, SET10, SET01, SET00). The ROM circuit 32a has two ROM units 32c, 32d. Each of the ROM units 32c, 32d has a fuse and an nMOS transistor that are connected in series 15 between an internal power supply line VII and a ground line VSS, and an inverter connected to a connecting node of the fuse and the nMOS transistor. The nMOS transistor is connected to the internal power supply line VII at a gate thereof to be constantly on and functions as a high-resistance resistor.

The ROM unit (32c or 32d) where the fuse exists outputs the fuse signal (FS1 or FS0) 20 at low level. The ROM unit (32c or 32d) where the fuse has blown out outputs the fuse signal (FS1 or FS0) at high level. Each of the two fuses is blown out or not blown out according to manufacturing specifications in the manufacturing processes of the pseudo SRAM, so that the decoder 32b sets only one of the setting signals to low level. Note that the tail numbers of the setting signals SET11, SET10, SET01, SET00 represent the logic of the fuse signals FS1, 25 FS0. For example, when the logic of the fuse signals FS1, FS0 is "10" in the binary number,

the setting signal SET10 maintains low level and the other setting signals SET11, SET01, SET00 maintain high level.

The reference voltage generator 30 has a plurality of resistors connected in series between the internal power supply line VII and the ground line VSS and also has a switch circuit 30a for connecting one of connecting nodes of the adjacent two resistors to an output node of the threshold voltage Vth1. The switch circuit 30a is constituted of a plurality of sets of a CMOS transmission gate and an inverter, and when the setting signal SET is at low level, the corresponding CMOS transmission gate turns on. In this example, four kinds of the threshold voltages Vth1 are generated according to the logic of the setting signals SET (SET11, SET10, SET01, SET00). The resistance values are set according to the four generated threshold voltages Vth1 respectively.

This embodiment has described an example where the reference voltage generator 30 is formed for each of the threshold voltages Vth1, Vth2. However, the plural resistors connected in series between the internal power supply line VII and the ground line VSS may be used in common for generating the threshold voltages Vth1, Vth2, thereby generating the threshold voltages Vth1, Vth2 using one reference voltage generator.

The same effects as those in the above-described first embodiment are also obtainable in this embodiment. Moreover, in this embodiment, the reference voltage setting circuit 32 and the switch circuit 30a enable the generation of the plural kinds of the threshold voltages Vth1, Vth2. Consequently, a pseudo SRAM having an optimum characteristic can be manufactured according to the fluctuation in manufacturing conditions or according to product specifications (power consumption specifications).

Fig. 10 shows an essential part of a third embodiment of the semiconductor integrated circuit of the present invention. The same reference numerals and symbols are used to designate the same elements as the elements explained in the first embodiment, and

detailed explanation thereof will be omitted. In this embodiment, a temperature detector 34 is different from the temperature detector 14 of the first and second embodiments. The other configuration is substantially the same as that of the first and second embodiments. Therefore, only the temperature detector 34 is shown in Fig. 10.

5 The temperature detector 34 is constituted of the temperature detector 14 shown in Fig. 5 plus a basic differential amplifier 34a. The basic differential amplifier 34a is disposed between a connecting node N10 of a resistor R1 and a bipolar transistor BP1 and an input node N11 of differential amplifiers 14b, 14c. The basic differential amplifier 34a compares a preset threshold voltage  $V_{th10}$  (basic reference voltage) and a detection voltage N10 to 10 output the comparison result as a basic detection voltage N11. The differential amplifier 14b compares a threshold voltage  $V_{th11}$  and the basic detection voltage N11. The differential amplifier 14c compares the basic detection voltage N11 and a threshold voltage  $V_{th12}$ .

Fig. 11 shows the operation of the temperature detector 34 shown in Fig. 10. The 15 basic detection voltage N11 changes to high level when the detection voltage  $N10 > V_{th10}$  (Fig. 11 (a)), and in a converse state, changes to low level (Fig. 11 (b)). Here, the threshold voltage  $V_{th10}$  is set to a median value of the threshold voltages  $V_{th1}$ ,  $V_{th2}$ .

The operations of the differential amplifiers 14b, 14c receiving the basic detection 20 voltage N11 and a flipflop 14d are the same as those in the first embodiment (Fig. 6). In this embodiment, the differential amplifiers 14b, 14c receive the detection voltage N10 generated by a temperature detecting unit 14a via a differential amplifier 34a. Therefore, the detection voltage N10 that gently changes can be converted to the basic detection voltage N11 that 25 steeply changes. This makes it possible to make a steep voltage change at nodes N14, N12 compared with that in the first embodiment.

The same effects as those of the above-described first embodiment are also obtainable in this embodiment. Moreover, in this embodiment, since the voltage change of the nodes N14, N12 can be made steep, a temperature detection signal TDET can be surely generated even when fluctuation in manufacturing conditions cause variances in 5 characteristics of the differential amplifiers 14b, 14c and the variances cause an offset voltage. As a result, it is possible to prevent malfunction of the temperature detector 34 and to thereby surely generate the temperature detecting signal TDET even in a pseudo SRAM whose specification is such that the threshold voltages Vth12, Vth11 (boundary temperatures Tth1, Tth2) are close to each other. Alternatively, even when the threshold voltages Vth12, Vth11 10 vary due to fluctuation of manufacturing conditions, it is possible to surely generate the temperature detecting signal TDET.

Fig. 12 shows a fourth embodiment of the semiconductor integrated circuit of the present invention. The same reference numerals and symbols are used to designate the same elements as the elements explained in the first and second embodiments, and detailed 15 explanation thereof will be omitted. The semiconductor integrated circuit of this embodiment is formed on a silicon substrate as a pseudo SRAM, using a CMOS process.

The pseudo SRAM has a reference voltage generator 36, a temperature detector 38, a refresh timer 40, and a reference voltage setting circuit 42 in place of the reference voltage generator 30, the temperature detector 14, the refresh timer 16, and the reference voltage 20 setting circuit 32 of the second embodiment. The other configuration is substantially the same as that of the second embodiment.

The reference voltage generator 36 generates four threshold voltages Vth1, Vth2, Vth3, Vth4 corresponding to boundary temperatures Tth1, Tth2, Tth3, Tth4. The temperature detector 38 compares a voltage detected according to the chip temperature of 25 the pseudo SRAM with the threshold voltages Vth1-4 to output 2-bit temperature detecting

signals TDET1-2 according to the comparison results. The refresh timer 40 changes the timer cycle according to the temperature detecting signals TDET1-2. This means that the generation interval (output frequency) of a refresh request signal RREQ is set according to the temperature detecting signals TDET1-2.

5 The reference voltage setting circuit 42 outputs 8-bit setting signals SET in order to initially set respective values of the threshold voltages Vth1-4 to be generated by the reference voltage generator 36. 2 bits of the setting signals SET are used to make the initial setting of each of the threshold voltages Vth1-4. The logic of the setting signals SET is fixed during manufacturing processes of the pseudo SRAM as in the second embodiment.

10 Fig. 13 shows the temperature detector 38 shown in Fig. 12 in detail. A temperature detecting unit 14a, differential amplifiers 14b, 14c, and a flipflop 14d for generating the temperature detecting signal TDET1 are the same as those in the temperature detector 14 (Fig. 5) of the first embodiment. Further, the temperature detector 38 has differential amplifiers 38b, 38c and a flipflop 38d for generating the temperature detecting signal TDET2.

15 An output (a detection voltage N31) of the temperature detecting unit 14a is inputted in common to the differential amplifiers 14b, 14c, 38b, 38c.

A generator for the temperature detecting signal TDET2 constituted of the differential amplifiers 38b, 38c, the flipflop 38d, and so on is the same as the generator for the temperature detecting signal TDET1 constituted of the differential amplifiers 14b, 14c, 20 the flipflop 14d, and so on. The differential amplifier 38b compares the threshold voltage Vth3 and the detection voltage N31 to output the comparison result to an output node N36. The differential amplifier 38c compares the detection voltage N31 and the threshold voltage Vth4 to output the comparison result to an output node N38.

25 Fig. 14 shows the operation of the temperature detector 38 and the refresh timer 40 according to the change in the chip temperature. The temperature detector 38 sets the

temperature detecting signal TDET1 to low level indicating a high temperature state when detecting that the chip temperature of the pseudo SRAM shifts from a low temperature to a high temperature to exceed the boundary temperature Tth1 (represented by the threshold voltage Vth1) (Fig. 14 (a, b)). Therefore, the temperature detecting signal TDET1 changes 5 from high level to low level only when the chip temperature exceeds the boundary temperature Tth2 and further exceeds Tth1. The temperature detector 38 sets the temperature detecting signal TDET1 to high level indicating a low temperature state when detecting that the chip temperature shifts from a high temperature to a low temperature to be lower than the boundary temperature Tth2 (represented by the threshold voltage Vth2) (Fig. 10 14 (c, d)). Therefore, the temperature detecting signal TDET1 changes from low level to high level only when the chip temperature becomes lower than the boundary temperature Tth1 and further becomes lower than Tth2.

Further, the temperature detector 38 sets the temperature detecting signal TDET2 to low level indicating a high temperature state when detecting that the chip temperature of the 15 pseudo SRAM shifts from a low temperature to a high temperature to exceed the boundary temperature Tth3 (Fig. 14 (e, f)). Therefore, the temperature detecting signal TDET2 changes from high level to low level only when the chip temperature exceeds the boundary temperature Tth4 and further exceeds Tth3. The temperature detector 38 sets the temperature detecting signal TDET2 to high level indicating a low temperature state when detecting that the chip temperature shifts from a high temperature to a low temperature to be lower than the boundary temperature Tth4 (represented by the threshold voltage Vth4) (Fig. 20 14 (g, h)). Therefore, the temperature detecting signal TDET2 changes from low level to high level only when the chip temperature becomes lower than the boundary temperature Tth3 and further becomes lower than Tth4.

25 The temperature detector 38 maintains the level of the temperature detecting signals

TDET1-2 when the chip temperature is between the boundary temperatures Tth1, Tth2 and between the boundary temperatures Tth3, Tth4. Further, when the chip temperature fluctuates around the boundary temperature Tth1, the boundary temperature Tth2, the boundary temperature Tth3, and the boundary temperature Tth4, the level of the 5 temperature detecting signals TDET1-2 does not change. The boundary temperatures are defined as Tth1 > Tth2 > Tth3 > Tth4.

The refresh timer 40 sets the generation interval of a refresh request signal RREQ long when the logic values of the temperature detecting signals TDET1-2 are "11". The refresh timer 40 sets the generation interval of the refresh request signal RREQ to a standard 10 value when the logic values of the temperature detecting signals TDET1-2 are "10". The refresh timer 40 sets the generation interval of the refresh request signal RREQ short when the logic values of the temperature detecting signals TDET1-2 are "00".

The same effects as those of the above-described first and second embodiments are also obtainable in this embodiment. Moreover, in this embodiment, the refresh frequency is 15 delicately varied according to the chip temperature, which makes it possible to prevent unnecessary operation of the refresh timer 40 and so on and to further reduce the standby current.

Fig. 15 shows a fifth embodiment of the semiconductor integrated circuit of the present invention. The same reference numerals and symbols are used to designate the 20 same elements as the elements explained in the first embodiment, and detailed explanation thereof will be omitted. The semiconductor integrated circuit of this embodiment is formed on a silicon substrate as a DRAM having a self-refresh function, using a CMOS process. The DRAM executes a read operation, a write operation, or a refresh operation (auto-refresh) in response to an external command CMD during a normal operation mode.

25 The DRAM executes the refresh operation during a self-refresh mode in response to

a refresh request signal RREQ that is internally generated periodically. The DRAM is used as a work memory mounted on, for example, a notebook personal computer.

The DRAM has a command input circuit 44, a reference voltage generator 46, a temperature detector 48, a refresh timer 50, and an operation control circuit 52 in place of 5 the command input circuit 10, the reference voltage generator 12, the temperature detector 14, the refresh timer 16, and the operation control circuit 24 of the first embodiment. The other configuration is substantially the same as that of the first embodiment.

During the normal operation mode, the command input circuit 44 (a command decoder) receives the command signal CMD (for example, a row address strobe signal /RAS, a 10 column address strobe signal /CAS, a write enable signal /WE, or the like) supplied via a command terminal. The command input circuit 44 decodes the received command signal CMD (a read command, a write command, or an auto-refresh command) to output an internal command signal ICMD for having a memory core 28 execute a read operation, a write operation, or a refresh operation (auto-refresh).

15 Further, when receiving a self-refresh command via the command terminal CMD, the command input circuit 44 outputs a self-refresh signal SREF as the internal command signal ICMD for shifting a chip from the normal operation mode to the self-refresh mode. The command input circuit 44 does not accept access requests (the read command, the write command) and the auto-refresh command during the self-refresh mode.

20 The reference voltage generator 46, the temperature detector 48, and the refresh timer 50 are activated for operation while receiving the self-refresh signal SREF. In other words, these circuits 46, 48, 50 stop operating during the normal operation mode. The circuits unnecessary during the normal operation mode stop operating, which enables reduction in power consumption of the DRAM. The basic functions of the reference voltage 25 generator 46, the temperature detector 48, and the refresh timer 50 are the same as those of

the reference voltage generator 12, the temperature detector 14, and the refresh timer 16 of the first embodiment.

When receiving the read command, the write command, or the auto-refresh command from the command input circuit 44 during the normal operation mode, the 5 operation control circuit 52 outputs a timing signal TIMING for having a memory core 28 execute the read operation, the write operation, or the refresh operation. When receiving the refresh request signal RREQ during the self-refresh mode, the operation control circuit 52 outputs the timing signal TIMING for having the memory core 28 execute the refresh operation. The operation of the operation control circuit 52 is the same as that of the 10 operation control circuit 24 of the first embodiment. In this embodiment, however, a read request or a write request does not conflict with a refresh request. Therefore, the operation control circuit 52 does not have an arbiter.

The same effects as those of the above-described first embodiment are also obtainable in this embodiment. Moreover, in this embodiment, the standby current 15 (self-refresh current) can be reduced also in the DRAM having the self-refresh mode.

Note that the above-described embodiments have described examples where the present invention is applied to the pseudo SRAM chip and the DRAM chip. The present invention is, however, not to be limited to such embodiments. For example, the present invention may be applied to a pseudo SRAM core and a DRAM core mounted on a system LSI.

20 The above-described embodiments have described examples where the present invention is applied to the pseudo SRAM or the DRAM. The present invention is not to be limited to such embodiments. For example, the present invention may be applied to a logic LSI and the like in which the cycle of an internal clock signal is changed according to the chip temperature.

25 Further, the above-described second to fourth embodiments may be applied to a

**DRAM instead of a pseudo SRAM.**

The invention is not limited to the above embodiments and various modifications may be made without departing from the spirit and scope of the invention. Any improvement may be made in part or all of the components.